A.I.A. File No. 5 m

Wet Walls and Efflorescence

What Efflorescence is and How to Avoid It

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WET WALLS AND EFFLORESCENCE

What efflorescence is and how to avoid it, with examples showing the results of neglect

By L. A. PALMER, Research Associate

Results of two investigations conducted at the National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., George K. Burgess, Director

AMERICAN FACE BRICK ASSOCIATION
130 North Wells Street, Chicago

NINETEEN TWENTY-EIGHT

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SUMMARY OF RESULTS

This summary has been prepared by the American Face Brick Association to present as briefly as possible the outstanding facts about the occurrence of efflorescence on masonry walls and how to avoid it, as determined by two investigations conducted for the Association at the National Bureau of Standards, U. S. Department of Commerce, Washington, D. C. It is of course impossible to treat this subject adequately in a summary, and there is no doubt that the short time needed to read the complete reports which follow will be most profitably spent. The 55 illustrations, occurring chiefly in Part II of the first report, will be found especially interesting. The investigations described were carried on by L. A. Palmer, Research Associate, under George K. Burgess, Director of the Bureau of Standards, and the Research Committee of the American Face Brick Association, composed of F. W. Butterworth, Chairman, Wm. C. Koch and L. B. Rainey. For additional copies of this book, write the American Face Brick Association, 130 North Wells Street, Chicago.

EFFLORESCENCE may occur upon the surface of any masonry wall as a whitish deposit. Whenever such efflorescence appears, it means that the wall contained both soluble salts—usually calcium and magnesium sulfates—and moisture.

These soluble salts may have been in any or all of the masonry materials used in the wall, in facing, backup or mortar. The moisture may have entered the wall during construction, through exposure to rain or snow. It may have penetrated from the earth at the base or from improperly flashed parapet walls at the roof. It may have come from leaky gutters and downspouts, or from the lack of drips on cornices and sills. It may have entered through poorly filled or cracked mortar joints in the wall.

Once in the wall, the moisture dissolves some of the salts present, and later passes to the surface when conditions become favorable for evaporation. Then, when evaporation takes place, the salts are left behind on the wall as efflorescence. No masonry material is always exempt from contributing to the development of noticeable efflorescence, but some materials contain much larger quantities of soluble salts than others, and consequently are much more important sources of trouble.

Prevention of efflorescence must begin with the design of the building, follow through the selection of materials and the methods of work during the construction period, and continue with maintenance of the structure after its completion. However, the methods recommended and the precautions necessary are merely those of good practice and do not involve radical departures from recognized standards except possibly in the case of adding a water-repellent to the mortar. But the neglect of certain simple precautions may bring very unsatisfactory results.

Wet walls serious fault

The great importance of excluding moisture from the wall is brought out in Part I of the report on "Wet Walls and Efflorescence," as follows (page 8):

"Aside from being the direct cause of efflorescence, an excessive amount of moisture in the materials of a wall accelerates disintegration of such materials through alternate freezing and thawing of this moisture in the wall. Damp interiors are often another undesirable condition attending the disintegration and occurrence of efflorescence. It is therefore seen that a study of efflorescence from the standpoint of proper design, construction and maintenance must of necessity involve also certain phases of the study of both disintegration of materials in walls and damp interiors. This is the most important reason for making a concentrated effort in all future construction to make and preserve dry walls."

Note that disintegration and damp interiors are only attendant circumstances. They are not consequences of efflorescence. The alternate freezing and thawing of moisture disrupts masonry and this happens whether or not there are any salts present in such masonry. The report continues:

"In view of such facts the manufacturers of face brick are at present outlining a future study of a great many of the factors involved in creating and maintaining the best possible conditions for their material in the walls where they are to be used. Obviously, since face brick must be used with many other materials in such walls, such a study involves not only the building units, brick, but also assemblages of units of brick together with units of various other materials.

"In the investigation of causes of and remedies for efflorescence on face brick walls (page 24), it developed that the soluble salts that would otherwise be present in clay products used in construction can be practically eliminated by the manufacturer of such materials by certain procedures in the drying and burning of his ware, together with the judicious use of barium compounds in his clay. These procedures are at present being generally used by the face brick industry and in part justify the difference in cost between face brick and the cheaper clay products, hollow tile and common brick used generally as backing up materials. From an economic standpoint, it is not always practicable for the manufacturers of common brick and hollow tile to adopt the procedures used by the face brick industry in eliminating soluble salts. From the standpoint of efflorescence it is therefore very essential that these back-

ing up materials be protected from excessive water penetration. These efforts on the part of face brick manufacturers to reduce the amount of salts in their own product will not alone suffice in eliminating efflorescence."

Occurrence of soluble salts

In the investigations at the Bureau of Standards, 55 types of face brick from as many different manufacturers in various parts of the United States were examined for soluble salts. Six types of common brick and four each of widely used limes, portland cements and bricklayers' cements were also studied. The majority of the face brick contained less than 0.05 per cent of soluble sulfuric anhydride (taken as the chemist's guide to the soluble salts present). This amount is ordinarily insufficient to cause efflorescence even under conditions favorable for its development.

Each sample of common brick exceeded this amount and the average of all six types was 0.16 per cent. The lowest figure for the limes was 0.5 per cent. The portland cements and bricklayers' cements also contained varying quantities of these salts, and in the tests reported under "Efflorescence on Face Brick Walls," page 24, each was found to develop efflorescence when used in certain panels with face brick which alone—that is, tested without mortar—did not develop efflorescence. Other investigations of limes and building limestones have established the presence in these materials of the same soluble salts found in brick.

In testing brick for soluble salts, the sample for analysis need not include any material taken from more than one-eighth of an inch below the exposed surface of the brick, as the amount of such salts is usually greatest there. (Bureau of Standards Technologic Paper No. 370, page 617.)

Making mortar water-repellent

Since water ordinarily penetrates into a wall through the mortar joints rather than through the brick or stone, careful study was given to methods of making the mortar water-repellent. The plan recommended is the addition of two per cent by weight of calcium or ammonium stearate to the cement, lime or mixture of the two used in the mortar. Mortars so treated were found to be very effective in preventing the passage of moisture in all cases wherein only ordinary capillary forces obtain. While best practice would call for the use of stearate in mortar for backing as well as facing materials, it is especially important that it be employed in laying up the facing where the joints will be subjected to unusual exposure to driving rains or to water running down the surface of the wall. Joints of copings, window sills and parapet walls are all in need of especial care. In repointing joints that have cracked, water-repellent mortar is called for, as such joints are usually in highly exposed locations.

Calcium stearate is a powder which is mixed dry with the cement before adding sand and water, while ammonium stearate is a paste which is usually added to the mixing water. On the ordinary building job, the powder has proved the more practical and accurate to use with the equipment commonly available. These stearates can be obtained from chemical manufacturers, or integral waterproofing compounds containing them can be had through dealers in building supplies and branch offices of companies making such products. Every care should be taken to insure getting reliable material, and unless the particular product being considered is known to be satisfactory, it should be given suitable laboratory tests.

For addresses of manufacturers of stearates and integral waterproofing compounds containing them, write the American Face Brick Association, 130 N. Wells St., Chicago.

Other precautions for keeping walls dry

Specific recommendations that will help in preventing water from entering the wall are as follows: Use impervious copings, and point joints carefully with water-repellent mortar. Flash parapet walls, carrying the flashing completely through the wall one or two courses above the roof level, and waterproof the entire inner side of the wall. Likewise flash the washes of pediments and dormers.

Always provide adequate drips on all copings, cornices and window sills, making the grooves at least 5/8 inch wide and 3/8 inch deep, and provide projections of two inches or more so as to keep the drip away from the wall.

Use lug sills at windows, with slopes from the sides of the window to the opening and at right angles to the wall, and where practical avoid all joints in the sills. If brick sills are desired, flash under them with suitable metal flashing provided with drips. Employ projecting rows of brick very cautiously, and use water-repellent mortar for the joints beneath them. Avoid vertical joints in any sort of masonry wherever possible, and be sure water-repellent mortar is employed in such joints.

Protect walls under construction to prevent rain or melting snow from entering. Pile brick, tile, stone and similar materials on boards as delivered to the job to avoid contact with moist ground, and keep them covered. Keep gutters and downspouts in good repair, and make sure they are adequate to carry the water. Point up cracked joints very promptly. Coat the backs of retaining walls with an impervious layer, and keep brick building walls away from contact with the earth.

Classification of various types of efflorescence

While efflorescence is most common in the early spring, when walls saturated by melting snow or late winter rains are drying out, it may occur at any time of the year. It may appear quite generally over a wall, or be confined to certain small areas. Analysis shows there are these four conceivable conditions under which efflorescence may occur:

Condition A. Excessive water with only a normal amount of salts in the wall.

Condition B. Excessive water and an excessive amount of salts in the wall.

Condition C. Normal water and normal salts.

Condition D. Normal water but excessive salts.

Obviously the first two conditions, A and B, are the worst because disintegration may go hand in hand with

efflorescence, owing to the disruptive action of freezing and thawing. Condition B is of course worse than A.

Efflorescence occurring under Condition C is usually very mild, indeed. Condition D may cause some trouble, but like C, is usually only temporary and tends to disappear entirely as time goes on.

General efflorescence is apt to mean either condition B or D, where the wall contains excessive salts. Special efflorescence usually indicates Condition A, characterized by excessive water which is being allowed to penetrate the wall by some fault in design, construction or maintenance. Every instance of a leaking downspout, dripless sill or unflashed parapet wall may cause excessive water penetration.

Field study shows efflorescence preventable

As part of the field investigation of efflorescence, William C. Koch, of the Research Committee of the American Face Brick Association made an extensive study for the purpose of correlating the fundamental facts about the development of efflorescence with design, construction and maintenance of buildings. Finally, a detailed study was made of 250 cases of efflorescence and the usual accompaniment, wall disintegration. The Bureau of Standards report comments as follows:

"With but one or two definite exceptions, the 250 cases of discoloration and disintegration could have been prevented by either proper design, construction or maintenance. In some cases only one of these three factors was the direct cause, but usually there were two and in a number of cases all three were at fault.

"Efflorescence was observed on almost every type of building material . . . "

In emphasizing the necessity of promptly pointing up cracked mortar joints which are allowing penetration of water, the report says:

"Where prompt pointing up was not done and where the condition had lasted over a period of years, disintegration of the mortar joints almost invariably had occurred. In any case where underburned brick had been used, these also had become disintegrated."

The action of sulfur dioxide in accelerating the disintegration of certain masonry materials is well known, and must be considered in cities burning bituminous coal. Snow water may be sufficiently acid to attack the lime of mortar or certain limestones, but tests made at the Bureau of Standards have shown face brick highly resistant to solutions of sulfur dioxide in water and even to fairly concentrated acid solutions, such as ten per cent hydrochloric, sulfuric and nitric acid. However, the need of prompt pointing up of mortar joints is apparent.

Recapitulation of results of investigation

As summing up the results of the entire study of efflorescence on masonry walls, the following recapitulation of his report by L. A. Palmer is worthy of careful attention (page 24):

"The purpose of the foregoing is to point out the fact that in the main, the immediate cause of efflorescence and often too of wall disintegration is excessive penetration of moisture into the wall. The field work supplemented the fundamental work that had already been done and that had established the fact that hardly any masonry material is exempt from the possibility of containing soluble salts in quantity such that it may under favorable conditions contribute to the development of noticeable efflorescence. The favorable conditions are wet walls.

"With but one or two definite exceptions, all of the large number of instances of efflorescence and in some cases wall disintegration that were studied could have been prevented had due consideration and care been given to the proper design, construction and maintenance of these buildings.

"A few examples of such preventable instances of efflorescence have been shown. Some details in way of design, construction and maintenance which, had they been observed and remedied, would have prevented the occurrences of efflorescence as illustrated by photographs, have been mentioned. There are many more of such details and it is assumed that the architect and builder are more familiar with them than is any one else.

"Efflorescence can become very noticeable on the wall of a building composed of brick or other masonry materials that are exceptionally low in soluble salt content if an excessive amount of water enters that wall.

"Any efflorescence appearing on the wall of a building that is suitably designed, constructed and kept in repair in order to avoid excessive water penetration, will be due to rare and abnormal conditions. It will in time gradually diminish and finally disappear. It will never recur under normal conditions even though the soluble salt content of the entire wall be higher than is normally the case. Prolonged and heavy wind-driven rains will bring out efflorescence on almost any wall, but this efflorescence is of the temporary nature described, is usually of short duration, and is generally unaccompanied by disintegration of joints.

"The effort on the part of manufacturers of face brick to develop products as free as possible from soluble salts (even if the goal, complete elimination, could be attained) will not in itself insure against the development of efflorescence on walls. Their work must be supplemented by a concentrated effort on the part of architects, builders and owners to keep the walls as dry as possible. It is also very necessary that manufacturers of the other building materials used in walls with the face brick be equally concerned with the question of soluble salts in their materials.

"Means of preventing efflorescence by keeping the walls dry have been outlined. It is hoped that architects and builders generally will proceed much further with this study and that the face brick industry will have their full co-operation in keeping dry the face brick walls of buildings yet to be constructed."

WET WALLS AND EFFLORESCENCE

(Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce)

I. Certain Fundamental Principles

THE fundamental cause of efflorescence on the exterior walls of buildings has been found to be generally due to soluble salts in masonry materials. ([1], [2], [3] and [4].)

No masonry material is always exempt under all conditions from contributing to the development of noticeable efflorescence on the exterior surface of the wall of a building. This is true whether such material be used either in the facing or among the backing up materials of the wall.

In the investigation[2] conducted by the American Face Brick Association at the National Bureau of Standards, 55 types of face brick from as many different manufacturers in various parts of the United States were examined for soluble salts. Incidentally, during this investigation six different types of common brick were similarly examined.

The majority of the face brick contained less than 0.05 per cent of soluble sulfuric anhydride, an amount insufficient to cause efflorescence under conditions favorable for such. The soluble salt content of the common brick exceeded somewhat this amount in all six cases, the average being 0.16 per cent. During this same investigation, four each of widely used limes, portland cements and bricklayers' cements were studied in order to determine their tendencies to develop efflorescence. It was found that these materials used as mortars in panels constructed with the 55 different types of face brick did actually contribute to efflorescence on the panels. The lowest sulfuric anhydride content of the four limes used was 0.5 per cent. This was mainly in the form of calcium sulfate, a soluble salt. The portland cements studied contained varying amounts of calcium sulfate of necessity added by the manufacturer to retard the set of the cement. All of the bricklayers' cements contained appreciable quantities of soluble salts. The behavior of these mortar materials in the panel tests is discussed[5] in the report to architects and users.

J. S. Rogers[4] investigated 35 commercial chemical limes which are generally conceded to be at least as free from soluble sulfates as the limes used for building purposes. He found these limes to contain from a trace to 1.50 per cent of sulfuric anhydride and suggests that this was introduced by burning limestone with coal containing sulfur. It is reasonable to assume that a considerable portion of this sulfuric anhydride in these chemical limes was in the form of calcium sulfate, a soluble salt very often present in the efflorescence material.

In Bureau of Standards Technologic Paper 349, pages 540 et seq., it is shown that the sulfates of calcium and magnesium sometimes contained in brick and mortar materials, are also contained in various limestones used in the building industry. It is further shown in this publication (pages 528 et seq.) that soluble organic material, causing a brown discoloration, is often present in such limestones.

Two facts must be well understood. First, the soluble salts are not confined to any one building material, but are widely distributed among practically all of such materials and, second, the condition, wet walls, is most favorable for the development of efflorescence produced by such salts.

Thus the wide occurrence of these soluble salts among various building materials becomes apparent. It is essential that this fact be borne in mind if there is to be co-operation on the part of all manufacturers and producers of masonry materials with architects and builders. They must also use precaution to reduce the amount of moisture penetration into walls containing these salts and thereby overcome this annoyance, efflorescence.

Wet walls also accelerate disintegration

Aside from being the direct cause of efflorescence, an excessive amount of moisture in the materials of a wall accelerates disintegration of such materials through alternate freezing and thawing of this moisture in the wall. Damp interiors are often another undesirable condition attending the disintegration and occurrence of efflorescence. It is therefore seen that a study of efflorescence from the standpoint of proper design, construction and maintenance must of necessity involve also certain phases of the study of both disintegration of materials in walls and damp interiors. This is the most important reason for making a concentrated effort in all future construction to make and preserve dry walls.

In view of such facts the manufacturers of face brick are at present outlining a future study of a great many of the factors involved in creating and maintaining the best possible conditions for their material in the walls where they are to be used. Obviously, since face brick must be used with many other materials in such walls, such a study involves not only the building units, brick, but also assemblages of units of brick together with units of various other materials.

In the investigation of causes of and remedies for efflorescence on face brick walls[5], it developed that the soluble salts that would otherwise be present in clay products used in construction can be practically eliminated by the manufacturer of such materials by certain procedures in the drying and burning of his ware, together with the

[1]Efflorescence and Capillary Fissures in Cement Mortars, "Rock Products", Vol. 30, Feb. 5, 1927, Page 83.
[2]Cause and Prevention of Kiln and Dry House Scum and of Efflorescence on Face Brick Walls, L. A. Palmer, Bureau of Standards Technologic Paper No. 370.
[3]The Physical Properties of the Principal Commercial Limestones Used for Building Construction in the United States, D. W. Kessler and W. H. Sligh, Bureau of Standards Technologic Paper No. 349, pages 540 et seq. Also pages 526 et seq.
[4]Composition of Commercial Chemical Limes, J. S. Rogers, "Industrial and Engineering Chemistry," Vol. 19, Oct. 1927, Page 1157.
[5]Efflorescence on Face Brick Walls, L. A. Palmer, Special Report to Architects and Users of Face Brick. (See page 24 of this book.)

judicious use of barium compounds in his clay. These procedures are at present being generally used by the face brick industry and in part justify the difference in cost between face brick and the cheaper clay products, hollow tile and common brick used generally as backing up materials. From an economic standpoint, it is not always practicable for the manufacturers of common brick and hollow tile to adopt the procedures used by the face brick industry in eliminating soluble salts. From the standpoint of efflorescence it is therefore very essential that these backing up materials be protected from excessive water penetration. These efforts on the part of face brick manufacturers to reduce the amount of salts in their own product will not alone suffice in eliminating efflorescence.

Mortar made water-repellent by stearates

It was further developed during the above mentioned investigation ([2] and [5]) that the addition of an amount of either calcium or ammonium stearate with mortar materials reduced the extent to which they contributed to efflorescence. These two stearates render the mortar more water-repellent and an amount of either stearate equal to two per cent by weight of the cement or of the lime or of the lime plus the cement, if both cement and lime are used, is suggested. This treatment will practically prevent water penetration of the mortar due to capillary forces only.

It must, however, be borne in mind that the original moisture introduced during construction and contained in mortar so treated may be subjected to freezing to an extent sufficient to cause cracking of the mortar joints. Cracking of mortar joints containing the water-repellent materials may also occur as a result of settlement. Hence it is seen that no chemical treatment of materials will alone suffice. Prompt pointing up is required in this case if the mortar so treated is to maintain its original water-repellent property.

Water brings salts from wall interior

Water which has penetrated to the interior of a wall subsequently usually finds its way through the pores of the masonry to the face brick and there evaporates, depositing any salts which it has taken into solution from the backing up materials. It may not occur to one who has not studied the subject that any material other than that which he sees has contributed to the unsightly appearance of the wall. The salts thus being left on the face brick may lead one to conclude that the face brick are directly responsible, whereas they may have been practically free from soluble salts originally.

Summing up, it is seen that whereas the fundamental cause of efflorescence is the presence of soluble salts in the materials of the wall, the immediate cause is excessive moisture penetration into the wall. To avoid the latter condition requires the full cooperation of architects and builders as well as manufacturers of all masonry materials.

Analysis of wall conditions

For convenience, the conditions obtaining generally in the occurrences of efflorescence may be classified as follows:

Excessive water, normal salts

A. The condition: more than the normal or usual amount of water penetration of a wall containing a normal or average amount of soluble salts, the excessive water penetration being due to either faulty design, construction or maintenance or to combinations of these undesirable conditions.

Excessive water, excessive salts

B. The condition: more than the normal or usual extent of water penetration of a wall containing more than the usual amount of soluble salts, the high degree of water penetration being due to the same causes given under A.

Normal water, normal salts

C. The development of efflorescence attended by the condition: normal amount of water penetration of a wall containing a normal or average quantity of soluble salts.

Normal water, excessive salts

D. The appearance of efflorescence with the condition: normal water penetration of a wall containing a relatively large amount of soluble salts.

In the above classifications, "normal water penetration" and "normal or average amount of soluble salts" are only relative and arbitrary terms. No one has defined either condition. However, it is reasonable to hypothesize the existence of such conditions. Most careful observers and practically all architects and builders will recognize an extreme condition as regards water penetration. Most chemists familiar with building materials will recognize an extreme condition if the average salt content of the materials in the wall is greater than two per cent by weight of total mass of materials and another and highly favorable extreme condition if the salt content is below 0.01 per cent of the total weight of masonry. Either condition will seldom be realized.

Cases involving excessive moisture most frequent and most serious

Normal or average water penetration is exceeded by every instance of a leaking downspout, dripless sills, defective flashing of parapet walls, etc. If one were to estimate as to which of conditions, A, B, C and D predominate in the numerous instances of efflorescence, he would, following an extended field study, most likely conclude that conditions A and B obtain in by far the majority of cases. There are certain other things also that would become evident after such a study. It would be noted that conditions A and B are the ones most usually attended by disintegration of the wall. It is evident that in all cases of excessive water penetration, alternate freezing and thawing are especially severe and disrupt the masonry in time.

Furthermore, after long and constant observation of buildings which develop efflorescence under the conditions, C and D, the observer will note that such occurrences are usually temporary. The efflorescence will in such cases gradually diminish more and more and finally never again appear. In these instances also one seldom notes any wall disintegration. This would indicate that wall disintegration is not a consequence of efflorescence but rather that it is an attendant circumstance, the two, efflorescence and disintegration usually occurring simultaneously under the conditions A and B and from the same immediate cause, i.e., excessive water penetration of the wall.

If brick are used which have had no barium treatment or if the drying and burning conditions were not so controlled as to insure their having a low soluble salt content, there will result then either condition, B, the worst of the four conditions, or condition D, which though better than B is yet very undesirable.

Condition A is second in undesirability only to B. It is chiefly within the power of architects and builders to eliminate condition A. To relieve condition B requires effort on the part of producers of masonry materials as well as architects and builders. The producers alone are responsible for condition D.

Condition C is the best of the four. Efflorescence appearing under this condition is at the worst only temporary and usually it is little more than barely noticeable.

Melting snow may saturate walls

It often happens that certain structural or maintenance defects on buildings are so located that saturation of the walls at such places can only occur through the melting of snow. On account of large overhangs, such locations are amply protected from moisture in the form of rain. Nevertheless, driven snow can readily accumulate at these places. When melting, this snow will saturate the walls beneath the overhangs and produce efflorescence and disintegration in such locations during early spring. This is one of many reasons for the great prevalence of efflorescence during the early spring season.

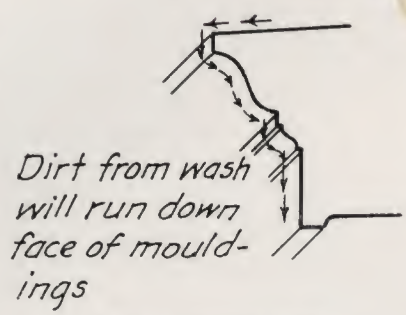

Figure 1. Conventional profile

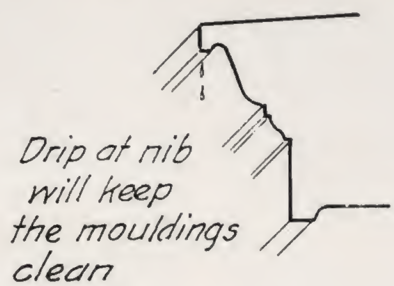

Figure 2. Improved profile

It can be noted in almost any city that along with the usual white efflorescence, on the same building there may be seen unsightly stains on the faces of belts and cornices. In most cases, failure to provide drips at the nibs of the projecting cornices is the direct cause of the streaks and stains on the stone, terra cotta, etc. Solid particles of soot settle on the washes, become softened by rain and run down the face of the moldings. These discolorations are cumulative and in most manufacturing cities become jet black. The soot contains more or less of sulfur which gives to water in contact with it acidic properties which may be a factor in disintegration of mortar joints, making soluble otherwise insoluble material.

Drips greatly reduce water penetration

While it is true that drips at the nibs may in some cases slightly modify the customary proportions of certain members, the advantage gained in reducing water penetration is sufficient to outweigh any such objection. Quoting from Bureau of Standards Technologic Paper No. 132: "Where rain falls on the top surface of a projection, it runs over the outer edge and following the lower surface reaches the wall which becomes soaked for some distance below. Also snow which is allowed to remain on these projections finally melts and causes the same difficulty. By the simple method of 'throating'—that is, making a groove in the lower surface of projecting members — this difficulty is overcome, as the water when it reaches this groove drops to the ground." Further than this, only a little consideration is necessary to clearly see that a small drip groove is of little value, as the droplets of water can span such. It is good practice to make the grooves at least ⅝″ wide and ⅜″ deep. Another necessary precaution is to have the projection at the rear of a coping at least 2″ to give room for a drip of this size and to keep the drip away from the wall. **FIGURE 1** illustrates the conventional profile. **FIGURE 2** is no less pleasing to the eye as regards profile and will serve to keep the moldings clean, whereas water and dirt will run down the face of the moldings of **FIGURE 1** and disfigure it as well as the face brick or other materials below it in the wall.

II. Field Work

SUPPLEMENTARY to the work of finding necessary fundamental facts concerning the development of efflorescence, William C. Koch of the Research Committee of the American Face Brick Association, undertook an extensive study for the purpose of correlating these facts with the subjects of design, construction and maintenance. Certain buildings which were prone to develop efflorescence were observed carefully from season to season and some facts not at all obvious at first were brought out. Finally an intensive field study was made in which 250 cases of efflorescence and the usual accompaniment, wall disintegration, were studied and an attempt was made to interpret these data. With but one or two definite exceptions, the 250 instances of discoloration and disintegration could have been prevented by either proper design, construction or maintenance. In some cases only one of these three factors was the direct cause, but usually there were two and in a number of cases all three were at fault.

Efflorescence was observed on almost every type of building material. The efflorescence on stone which is more nearly the color of the stone was often not apparent until a close examination was made. This same efflorescence would have been very conspicuous had the stone been as dark in color as brick.

Prompt pointing up of mortar joints essential

In some instances the joints in the wall areas were carefully pointed up following the first few occurrences of efflorescence. Due to settlement, cracks often appeared and this condition augmented the penetration of water into the interior of the wall. Where prompt pointing up was not done and where the condition had lasted over a period of years, disintegration of the mortar joints almost invariably had occurred. In any case where underburned brick had been used, these also had become disintegrated.

In the atmosphere of cities consuming annually large quantities of bituminous coal, the sulfur dioxide so liberated in conjunction with water in the form of rain or melting snow may accelerate the disintegration of certain masonry materials. Parr[6] in discussing the prevalence of sulfur dioxide in the atmosphere makes the following statement:

"I recall a certain dwelling far removed from possible contamination by gases from coal fires where the window screens have remained continually in place for twenty years. The iron wire of which they are made is still whole and sound, whereas the iron wire screens of another dwelling in the center of the soft coal belt corroded and fell completely out of their frames after one winter season."

Professor Parr states further that the annual combustion of 600 millions of tons of coal, mostly bituminous, in the United States liberates approximately 40 billion pounds or 400 billion cubic feet of sulfur dioxide, most of which is concentrated in manufacturing centers. If sulfur dioxide from this source is in concentration sufficient to corrode an iron wire screen in one season, it very likely also would tend to corrode any masonry material containing lime, such as mortar or limestone. ([3] and [7]) All brick manufacturers know what sulfur dioxide will do to a clay containing limestone in a humid drying chamber.

Face brick resistent to acid solutions

On the other hand, the author has made numerous tests with concentrated solutions of sulfur dioxide in water on face brick. In all cases the solvent action of this reagent was negligible. In by far the majority of cases there was no solvent action whatsoever. In addition, the author immersed face brick in fairly concentrated acid solutions, such as ten per cent solutions of hydrochloric, nitric and sulfuric acids for periods of from ten days to two weeks. While these acids are sufficiently strong to rapidly dissolve certain limestones, the brick thus treated remained practically unchanged. It is reasonably safe to assume that underburned brick would not have been so resistent generally.

In the light of the above comments by Professor Parr, it is very likely that sulfur dioxide of the atmosphere can accelerate any decomposition of mortar joints initially begun by frost action or cracking due to settlement. Prompt pointing up of joints is, therefore, very necessary and further than this since pointing up is usually required on those portions of the wall most exposed to excessive moisture penetration, mortar containing the water-repellent stearates should be considered for such pointing up.

Snow water may hasten mortar disintegration

In connection with the field work, some analyses of snow water were made. In one instance water from melted snow accumulating over a period of three months in a small, open area in the city of St. Paul contained 0.005 per cent of sulfuric anhydride. This water was distinctly acid, the "pH" (logarithm of the reciprocal of the hydrogen ion concentration) being 3.5. Water of this acidity could easily attack the lime of mortar or certain limestones (forming soluble calcium sulfate) if left in contact with such building materials for considerable periods of time. Such water entering cracks due to settlement or frost action would tend to accelerate any disintegration of mortar. Here then is another possible source of efflorescence.

Careful and prompt pointing up of mortar joints is especially necessary in brick masonry as a safeguard against efflorescence, as observations showed. For example, consider two walls, one of stone and one of brick. The ratio of amount and number of exits (principally joints) in brick work to those in stone work is such as to

[6]Some Combustion Problems in their Relation to Public Health, Samuel W. Parr, "Industrial and Engineering Chemistry," Vol. 20, May 5, 1928, Page 454
[7]H. Pemberton, Journal Franklin Inst. Vol. 106, Page 62

promote freer flow of water in the wall of brick, carrying the salts to the surface. Furthermore, joints in stone are generally thinner than those in brickwork and the area of each joint in the latter case is consequently greater than in the case of stonework. These dimensional factors result in restricted flow of salt-laden water in the case of stone. This fact may account in part for the popular notion that limestone and sandstone contain very little of soluble material.

FIGURE 3 shows efflorescence on red sandstone. Water penetrated the wall, draining in from the small porch over this discoloration. In **FIGURE 4** there is seen efflorescence on both the brickwork and stone arches beneath the window jutting through the lower part of the roof. The design in this case is very favorable for carrying water into the wall at the area covered by the white salts. **FIGURE 5** shows again efflorescence on sandstone. Prompt pointing up of the cracks between mortar joints and stone due to settlement would have prevented this. **FIGURE 6** shows efflorescence on porch cheeks of concrete block due to seepage and splashing at the base and in addition to this, water has entered from the porch floor. Moisture also has progressed down the column from the cap of the porch pier.

Settlement cracks need immediate attention

It is reasonable to assume that cracking of joints due to settlement is more likely to occur at the bond of stone copings, sills, etc., than it is among the joints between the brick in a wall faced with brick. This assumption is more justifiable when stone or brick walls exposed to a normal amount of water penetration are being considered. Evidence for this assumption was found in many instances and **FIGURE 7** is an illustration of one. The brick being small units, the stresses induced by settlement tend consequently to be more evenly distributed than in the case of a wall built entirely of stone. In **FIGURE 7** although the construction was originally good, cracking became noticeable at the left end of the stone coping due to settlement. Water leaks through this crack and through similar ones not visible and particularly through the crack along the entire length of stone and back of same whence it easily penetrates to the face of the brick wall at the points where vertical joints in the stone and between the stone and the brick have disintegrated or have cracked open. A little pointing up should have been done promptly.

In this connection it is well to consider that the number of mortar joints per unit area of a brick wall, being considerably greater than the number of such in the same area of a wall built entirely of stone as above mentioned, water can therefore flow more freely into the wall built of brick on account of this larger area of mortar. Referring to **FIGURE 7**, there is then consequently more water penetration in the brick wall below the stone coping which has cracked loose from the mortar bond due to settlement than would have obtained were the wall built entirely of stone. It is not therefore that in the matter of proper maintenance more pointing up is required in a wall built of brick, but it is the fact that prompt pointing up is of especial importance. It is also apparent that there being more mortar material in the brick wall, any contribution which a given mortar makes to the development of efflorescence is greater in a brick than in a stone wall.

More consideration should be given to the future use of a building by those who design and construct it. **FIGURE 8** shows a creamery covered in places by efflorescence. A photograph of this structure taken two years previous to the time of obtaining the one here given

Figure 3. Efflorescence on red sandstone, below porch.

Figure 4. Efflorescence on both brickwork and stone arches.

Figure 6. Efflorescence on concrete block.

Figure 5. Prompt pointing up of cracks in the mortar joints would have prevented this efflorescence (on sandstone).

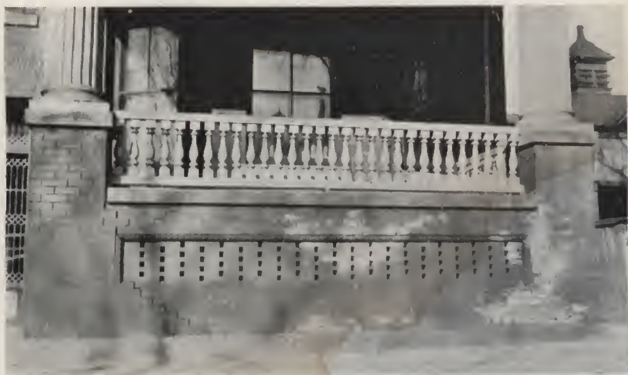

Figure 7. The stone coping has broken loose from the adjoining masonry, allowing water to enter the brickwork.

Figure 10. Leaking downspouts are frequent sources of water penetration, leading to efflorescence.

Figure 8. Water condenses on the inner walls of this creamery except in the office, which is at the right.

Figure 9. Closer view of wall shown above. Note disintegration of mortar joints.

also shows efflorescence appearing on the same parts of the wall as those covered with such in this case, two years later. Water condenses inside where operations are carried on. The middle portion of the exterior wall to the right is free from efflorescence. This area is the outer wall of the company's office and consequently there was a dryer interior at this locality. The efflorescence in this instance could possibly have been prevented altogether or at least considerably reduced by waterproofing the entire inner walls of the humid rooms. Waterproofing the exterior surface of these walls would merely result in a progressive accumulation of the efflorescence at those areas where the exterior coating of waterproofing material is defective. Such areas are always developed to a greater or lesser extent.

Among the various types of faulty maintenance, leaking rain leaders and gutters are very numerous. **FIGURES 9 and 10**, photographs of the same wall, amply illustrate the disintegration induced first by cracks due to settlement and later accelerated by the excessive penetration of water due to a leaking downspout. In this instance, the mortar joints have disintegrated. The courses of brick projecting outward from the wall add to the excessive accumulation of moisture. This point relative to design will be further illustrated in this report. Again, note the efflorescence near the downspout in **FIGURE 11.** This wall is of limestone and its color is nearly the same as that of the salts of efflorescence.

Figure 11. Efflorescence closely follows the downspout on this limestone wall, showing penetration of moisture.

Gutter drains should be higher toward the building. A few instances were noted where the reverse was the case and in many instances, the level toward the wall was the same as that farthest from

Figure 12. Excessive moisture has here caused the distintegration of paint, as in numberless instances.

Figure 13a. Seepage and splashing have brought about extensive stucco disintegration at the base of this building.

Figure 13b. In addition to causing efflorescence, excessive water penetration has here resulted in disintegration of the stucco, which has fallen off, exposing the brickwork beneath.

Figure 14a. The unusually severe exposure of this wall has resulted in marked efflorescence.

Figure 14b. In this view of the same wall, note the peeling of paint and the failure of mortar joints.

Figure 14c. Here is the final collapse of part of the wall shown in the above illustrations.

Figure 14d. In this addition to the same wall, both the stucco cover and the mortar joints are disintegrating.

the wall. It is also necessary that gutters and drains be of ample capacity for carrying away water from heavy rains. Also, at the returns of porch roofs where overflow will result in discoloration and cracking of masonry material, special attention should be given to the design of gutters and downspouts. The end joints should be thoroughly protected with sheet lead, copper or other suitable flashings.

In order to illustrate the damaging effect generally of exposure of all building materials to an excessive amount of moisture, the accompanying photograph, **FIGURE 12,** is shown as a typical example of numerous instances observed of paint disintegration from this cause. **FIGURE 13a** shows disintegration of stucco at the base of a building brought about by seepage and splashing. The eaves are wide enough to protect most of the walls, but there is no protection at the base. The stucco was at the soil level originally. **FIGURE 13b** is another example of disintegration of stucco resulting from excessive water penetration.

FIGURES 14a, 14b and 14c show in increasing order of magnitude the effect of needless exposure of a wall. Efflorescence is shown in (**a**), in (**b**) is seen efflorescence and disintegration of the mortar joints, and (**c**) shows the final collapse of the wall. **FIGURE 14d** shows an addition to the building made after that part illustrated by **FIGURES 14a, 14b and 14c** had shown signs of deterioration. By profiting partially by past mistakes in the way of design and construction, it is seen that in the newer part, **14d,** the brick are not covered by earth. There is a concrete base in this case. However, the design of the sills is wrong, they having no drips, and there are no eaves; hence, covering the brick with stucco brought no material benefit. It is seen that the stucco cover is beginning to disintegrate, showing the brick underneath. The mortar joints are also beginning to rapidly disintegrate. Note also the disintegration of paint in the illustrations, **14a** and **14b.** This is also likely due to the unusually severe exposure of the wall.

Figure 15. Maintenance alone is at fault in this instance—the gutters are defective.

FIGURE 15, unlike the cases **14a, 14b, 14c and 14d,** is a case of faulty maintenance only. Due to defective gutters, there has been more than normal penetration of water into the wall. If the bales are fixed, the next good rain will have washed off the efflorescence and it may not recur. **FIGURE 16** is another example of improper maintenance. The design and construction were all right in this case. The downspout is leaking and, what is worse, there has been no pointing up of cracks (due to settlement) at the top stone courses.

Figure 16. The downspout leaks, and settlement cracks above the stone set in the brickwork have not been pointed up, resulting in much efflorescence.

Excessive water penetration from lack of drips

A typical example of wrong design is shown in **FIGURE 17, a and b.** Both are pictures of the same building. There are no drips on the flat inclined stone caps at the top of the buttress piers and the inevitable result is in evidence.

Figure 17a. Efflorescence caused by failure to provide drips on the stone caps over the buttress piers.

Figure 17b. Another view of the same building illustrating the necessity for adequate drips.

Figure. 18. This general efflorescence, chiefly on the mortar joints, probably came from excessive salts in the wall.

Figure 19. Water has penetrated these walls of underburned brick, because of poor design and poorly constructed coping.

Figure 20. Flashing should be carried completely through the parapet wall to keep water from penetrating downward.

Figure 21. Efflorescence has appeared in this case below the water exit in the parapet wall.

Figure 22a. Defective flashing, absence of suitable drips and projections at the buttress tops caused this trouble.

Figure 22b. Faulty maintenance is also responsible in part for the efflorescence shown on this church.

It is very probable that condition D, namely normal water penetration of a wall containing more than the usual amount of salts, obtained in the case of the building, **FIGURE 18.** The efflorescence was in this case generally distributed over the wall. This building is new and the design and construction were good. It may be noted that the efflorescence was in this instance mainly on the mortar joints. It is likely that these salts were carried outward to the surface by evaporation of the moisture absorbed and entrapped during construction.

Brick walls need protection during construction

Mention should be made here of the need of protection of brick walls during the process of construction from avoidable exposure to moisture. The tops of unfinished walls should be well covered with canvas or tar paper at the end of each day's work.

Proper flashing essential

Defective flashing is one of the most numerous of the immediate causes of efflorescence and wall disintegration and often also there are in addition poorly designed and constructed copings. Wall copings, cornices, rails, chimney caps, etc., should be built of concrete, stone, terra cotta or metal with ample overhanging drip groove or lip, and watertight joints. **FIGURE 19** shows a building constructed of underburned brick, which have been subjected to freezing and thawing of water penetrating into the interior of the wall through poor design and poorly constructed coping. This building is old and it is likely that the underburned brick that have in this case disintegrated to some extent, were burned in scove kilns which in early days were fired with wood. **FIGURE 20** is a typical example of defective flashing on a parapet wall. Note the efflorescence below the water exit in the parapet wall illustrated in **FIGURE 21.** Considering the favorable conditions for excessive water penetration, there is remarkably little efflorescence on the exterior walls of the church, **FIGURES 22a and 22b.** Defective flashing, together with the absence of suitable drips and projections at the stone caps at the tops of the buttress piers, is directly accountable for the white efflorescence. Faulty maintenance has added to the deplorable condition.

In the case of parapet walls as illustrated by **FIGURE 20,** the flashing should be carried completely through the wall, one or two courses above the roof level. The parapet wall is then completely separated by an impervious membrane from the other portion of the wall and consequently water can not penetrate downward into the wall. Architects should also waterproof the entire inner side of the wall and should use impervious coping with carefully pointed joints. It is out of the province of this report to discuss the various details of design. These are subjects with which the architect is familiar. However, the accompanying illustrations show that these necessary precautions are often overlooked and neglected.

In an article entitled, "Keeping Buildings Dry," and in regard to discoloration on the underside of balconies, Cecil Fidler, Engineer of Standards, Atlantic Terra Cotta Company has stated as follows:

"It is almost impossible to make the deck of a balcony watertight by means of a cement or tile finish. A covering of sheet metal should be used in all cases. In flashing the tops of balcony slabs with sheet metal, it is necessary to run the flashing out to the nib if the best results are to be obtained. Quite frequently the floor of a balcony is properly flashed, but the flashing terminates in reglets in the base of the balustrade. This practice almost invariably results in the saturation of the balcony slab by water which finds its way in at the joints in the balustrade and runs down behind and underneath the flashing. By carrying the flashing underneath the base course, any water that enters at the joints of the balustrade can not penetrate to the balcony slab, and the soffit of the balcony is kept dry and unstained."

Figure 23. The stonework below the balcony is not protected by flashing and shows marked efflorescence.

In the case illustrated in **FIGURE 23,** there is no flashing at all on the balcony below which the efflorescence appears. The stonework is covered by large copings which communicate directly in a vertical direction with that part of the stonework showing the efflorescence. A number of the vertical joints in this coping have partially disintegrated.

Mr. Fidler further recommends the complete flashing of the washes of pediments and dormers to avoid the evils of saturation and makes the statement:

"While the use of sheet metal for the protection of mortar joints may entail some slight additional expense at the time of the erection of the building, it will be found more economical in the end because the cost of maintenance will be avoided."

Mortar joints often not water-tight

It became apparent during the field study that architects and builders were placing too much reliance on the mortar joints. Close inspection of many cases of wet walls showed that water was entering the mortar joints in the wash of the cornice and parapet coping. For some reason water-tight joints are not being produced by caulking and

Figure 24. A projecting metal flashing with drips should be placed below brick sills like those shown here.

Figure 25. Joints in the window sills have cracked, allowing excessive moisture to enter the brickwork below.

grouting. A number of things may be accountable for this condition of the joints, such as poor workmanship, inferior mortar or mortar that is too lean, disintegration through alternate freezing and thawing of the original moisture introduced during construction in late fall or winter, or cracking due to uneven settlement and thermal expansion.

Avoid vertical joints exposed to excessive moisture

Vertical joints exposed to an excessive amount of moisture as are those in window sills should be avoided as much as possible. FIGURE 24 is typical of what will follow if this precaution is not observed. This wall is of sand-lime brick and efflorescence is noticeable beneath the rowlock brick sills with many intervening mortar joints in each sill. Of course, there are no drips on such sills. If such sills must be used, there should be placed beneath such a sill a suitable metal flashing, projecting and with drips. FIGURE 25 shows a church whereon cracking and initial disintegration of joints, especially of the vertical ones, has occurred. As a consequence of the failure to observe these precautions, the brick above the stone belt line and beneath the sills are here being exposed to an excessive amount of moisture. It would have been better had the sills been in each case one solid piece of stone with a slope to the wall on each side. Furthermore such sills (lug sills) should project at least two inches and be provided with suitable drips. This also applies to the cornice.

FIGURE 26 illustrates protection against excessive water penetration at the sills. Note that each sill is a single unit and not two or three units with intervening vertical mortar joints. This illustration typifies the ideal drainage for sills. There are good drips underneath and an upward slope in each case from the window area toward the wall to left and right. The sills also project more than two inches. Good cornice and well pointed joints are also characteristic features of this building. Another model of good design is illustrated by FIGURE 27. Here there are good drips on sills which are single units with no vertical joints. Other desirable features are the wide eaves, the cornice reentering, protection against seepage at the base by having the brick on stone some distance from the soil and the rain water leaders extending to the ground thus avoiding splashing.

Projecting courses may cause efflorescence

Projecting courses of brick such as the rowlock or soldier courses apparently intended to enhance artistic beauty in a wall, in reality are most conducive to discoloration as well as to disintegration. Where such courses of brick are laid in a wall, there should be ample protection against excessive water penetration. The vertical courses of brick illustrated in FIGURE 28 are being exposed to excessive moisture. Efflorescence will inevitably result on such exposed areas and what is far more undesirable, disintegration will always be accelerated when mortar joints are so exposed. Note in this instance the marked efflorescence on

Figure 26. This illustrates good drainage for sills, with adequate drips and the proper slopes at the ends.

the mortar joints. Lime putty mortar was used. The combination, poor materials together with poor design from the standpoint of excessive moisture penetration, brings about condition B, the most undesirable of the four mentioned. In this particular instance, the brick are remarkably free from efflorescence, considering the extent of exposure to which they have been subjected. In time, however, the soluble salts on the joints as illustrated may be carried by moisture over the face brick, and one who observes the wall then for the first time may think that the brick are directly responsible for the efflorescence. **FIGURE 29** shows a corbelled area on a new building that is dark with moisture. This may be expected eventually to result in disintegration of joints and efflorescence similar to conditions illustrated in **FIGURE 33.** The small recess below the window sill collects a maximum of water for the vertical joints below.

Figure 27. This building illustrates good design as regards sills, wide eaves, cornice and protection at the base.

Figure 28. The projecting courses of brick shown here receive excessive moisture.

Figure 29. The corbelled area is dark with moisture, and as the building ages, will doubtless show efflorescence and disintegration of joints.

In the design of all walls built of brick some consideration should be given to protection against water penetration rather than to but one thing, namely artistic appearance. To corbel out with one or more courses of brick or any other masonry material, is always a dangerous procedure unless such projecting brick courses are to be so situated as to be amply protected from undue exposure to moisture penetration.

Figure 30. By modification of design, greater protection can be given masonry materials in cases like this.

Protect masonry through attention to design

It is believed that a realization of what can happen through improper design will go farther toward correcting this evil than will a recital of a large number of details necessarily involved in construction planned to protect the wall. The builder is familiar with these various details and due probably to the fact that he relies too much upon the weather resistance properties of all masonry materials he too frequently does not consider the possibility of modifying the design so as to protect them more. Such an example as the accompanying illustration, **FIGURE 30,** typifies such a tendency on his part. Here again are the maximum number of exposed vertical joints.

From this illustration to the next, **FIGURE 31a,** there is added the further undesirable condition, soil in immediate contact with the brick in the retaining wall. To have put tar or tar paper back of this wall or still better to have dug a trench back of this wall, lining the trench with impervious concrete and then to have filled the trench with gravel would have been an additional expense well worth while. Within a short time it will be necessary to rebuild this wall and this procedure will cost considerably more than would the initial precautions.

Figure 31a. Moisture has entered this wall from the soil, which is in contact with the brickwork.

Walls severely exposed

The subject, retaining walls, is interesting. It is here that masonry materials are given the most severe exposure if not properly protected. **FIGURE 31b** shows a coping of well burned brick on a retaining wall. Even well-burned brick or other good materials must have sufficient drainage if they are to resist frost action. The result here is due to lack of proper drainage. **FIGURE 31c** is another retaining wall that has been pointed up twice and a third operation of the kind is in need of being done. **FIGURE 31d** is especially interesting. Below each disintegrated vertical joint in the cap of this wall, there is a crack in the solid concrete below. Perhaps no comments on **FIGURE 31e** are required. **FIGURE 31f** shows how mortar has disintegrated under a cap with no drip. This is also part of a retaining wall.

Figure 31b. In retaining walls, the exposure is especially severe. Even well-burned brick, such as were used here, must have adequate drainage to resist frost action.

Figure 31c. The mortar joints in this wall have been pointed up twice and need attention again. Direct contact with moist ground at the back of the wall, without insulation or proper drainage, is responsible for this trouble.

This same principle applies in the construction of chimneys. Chimneys are peculiarly vulnerable to severe weathering conditions. The accompanying photograph, **FIGURE 32** is but one of a large number of instances of the sort. Here again too much dependence was placed upon the vertical mortar joints in the brick at the cap. Such a chimney should have had a stone cap with good projection and furnished with drips of wide and deep grooves. The thin covering of stucco in this case has not endured the test.

As final illustrations of a combination of faulty design, construction and maintenance, **FIGURES 33** and **34** should be self-explanatory. **FIGURE 33** is a small portion of the building of which **FIGURE 34** is a more complete view, not however showing the portion shown in **FIGURE 33.** This closeup indicates what may be expected in years to come in wall areas like that shown in **FIGURE 29,** which is on a new building. Corbelling such as illustrated in these two pictures usually leads to excessive moisture penetration.

In **FIGURE 33** it may be noted that both mortar joints

and a window sill are disintegrating. Repair and pointing up are badly needed. Leaking downspouts, defective flashing both at the chimney base and in the parapet walls, projecting courses of brick with vertical joints exposed, poorly designed drips on sills (such being too shallow and so close to the wall as to be ineffective), the sills themselves being of soft porous sandstone and not weather resistant and the truncated water exit (**FIGURE 21**, same building), were the immediate causes in this instance of the efflorescence attended by disintegration.

Figure 31d. The vertical joints in the coping have disintegrated, and below each a crack has formed in the concrete.

Figure 31e. An endless number of retaining walls in varying stages of failure might be shown.

Figure 31f. Under this cap, which has no drip, the mortar has disintegrated badly. This is also part of a retaining wall.

Figure 32. Chimneys receive particularly severe exposure. The vertical mortar joints here have allowed water to enter between the stucco and the brick.

Figure 33. Corbelling of the brick is the chief reason for the failure at the right, whereas the trouble directly under the left window is due in large measure to the sill.

Figure 34. This efflorescence has resulted from a number of clearly recognizable faults of design, construction and maintenance. Figure 33 shows a closeup view of another part of this building.

Again, to further illustrate combined faulty design, construction and maintenance, consider **FIGURES 35a, 35b, 35c** and **35d,** all pictures of the same building although parts of an adjacent building are seen in **FIGURES 35a** and **35c.** This was originally Condition B, without doubt. Kiln run common brick, a portion of which are underburned, compose the wall. **FIGURE 35d** shows the extent to which these brick as well as the intervening mortar joints near the soil have disintegrated. Efflorescence, very noticeable in the past, is becoming less noticeable at present while disintegration progresses. The walls have received quantities of water to wash out the salts for the most part. Galvanized iron which corrodes comparatively readily was used for flashing of the parapet wall which is about eight feet above the roof. There is both seepage and splashing, causing saturation of the lower wall. The coping is poorly designed. There are downspouts but these are inside the building and have undoubtedly become clogged. As a result, the overflow spouts have been called on to do the work with the results herein illustrated. As the joints progressively disintegrate the degree of saturation during a wet season increases. Below the wide recesses in the wall are projecting header courses of brick. It would be difficult to devise a more favorable condition for entrapping the maximum amount of moisture. Horizontal exposures are here unprotected by either sloping or by drips.

Figure 35a. This and the next three illustrations all show parts of the same building.

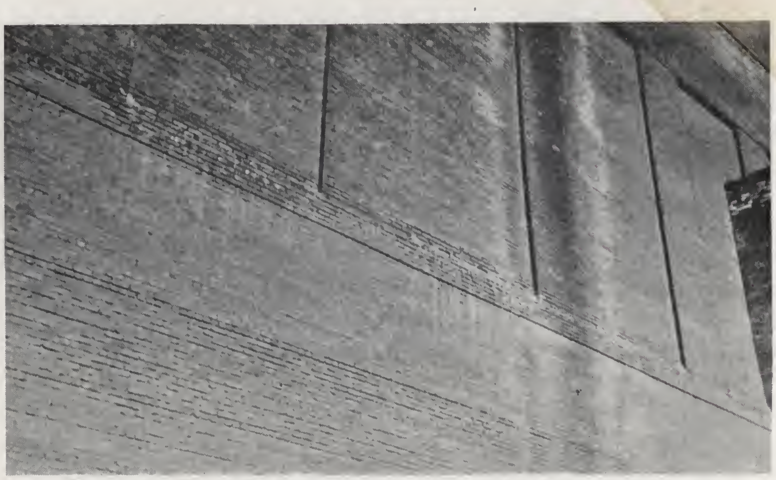

Figure 35b. The walls of this structure are composed of kiln run brick, some of which are underburned.

Figure 35c. Disintegration progresses while efflorescence becomes less marked as the soluble salts are washed out.

Some consideration might also be given finally to the analogous weathering of rock in nature. In connection with the following illustrations, one might make the appropriate statement: "Nature destroys her own." In **FIGURE 36a** can be seen in the distance across the river, the result of frost action, supplemented by erosion by water and wind. **FIGURES 36b, 36c,** and **36d** give one some notion as to the tremendous forces brought to bear in repeated freezing and thawing. Dynamite could hardly do more. These stones, of course, had no drips. The sandstone base illustrated in **FIGURE 37** is almost as much at the mercy of the elements. **FIGURE 38** shows a bridge railing without drip or enough slope. One might go on indefinitely, but it is hoped that the preceding illustrations show that there is required today more consideration of the subject, water penetration, in the building industry. Reduce water penetration and efflorescence will diminish in any case, whether there is a great deal of soluble salts or whether such salts are in very small quantity in the masonry. Best of all, there will also result far less tendency toward disintegration and this after all is a far more serious incident than is efflorescence.

Figure 35d. This closeup reveals the extent to which the mortar joints and even the brick have disintegrated.

Figure 36b. Viewed close at hand, the destruction wrought by repeated freezing and thawing is seen to rival the power of dynamite.

Figure 36a. Talus slopes such as this are common sights below cliffs of solid rock, along shore lines everywhere, for frost action is a relentless force, initiating the process of disintegration and opening the way for erosion by water and wind.

Figure 36c. Another type of rock broken up by frost action.

Figure 37. Moisture penetrating this sandstone base has begun its powerful disintegrating action.

Figure 36d. Still another variety disintegrated by frost.

Figure 38. This bridge railing has no drips and too little slope to dispose of the water.

Summary

The purpose of the foregoing is to point out the fact that in the main, the immediate cause of efflorescence and often too of wall disintegration is excessive penetration of moisture into the wall. The field work supplemented the fundamental work that had already been done and that had established the fact that hardly any masonry material is exempt from the possibility of containing soluble salts in quantity such that it may under favorable conditions contribute to the development of noticeable efflorescence. The favorable conditions are wet walls.

With but one or two definite exceptions, all of the large number of instances of efflorescence and in some cases wall disintegration that were studied could have been prevented had due consideration and care been given to the proper design, construction and maintenance of these buildings.

A few examples of such preventable instances of efflorescence have been shown. Some details in way of design, construction and maintenance which, had they been observed and remedied, would have prevented the occurrences of efflorescence as illustrated by photographs, have been mentioned. There are many more of such details and it is assumed that the architect and builder are more familiar with them than is any one else.

Efflorescence can become very noticeable on the wall of a building composed of brick or other masonry materials that are exceptionally low in soluble salt content if an excessive amount of water enters that wall.

Any efflorescence appearing on the wall of a building that is suitably designed, constructed and kept in repair in order to avoid excessive water penetration, will be due to rare and abnormal conditions. It will in time gradually diminish and finally disappear. It will never recur under normal conditions even though the soluble salt content of the entire wall be higher than is normally the case. Prolonged and heavy wind-driven rains will bring out efflorescence on almost any wall, but this efflorescence is of the temporary nature described, is usually of short duration, and is generally unaccompanied by disintegration of joints.

The effort on the part of manufacturers of face brick to develop products as free as possible from soluble salts (even if the goal, complete elimination, could be attained) will not in itself insure against the development of efflorescence on walls. Their work must be supplemented by a concentrated effort on the part of architects, builders and owners to keep the walls as dry as possible. It is also very necessary that manufacturers of the other building materials used in walls with the face brick be equally concerned with the question of soluble salts in their materials.

Means of preventing efflorescence by keeping the walls dry have been outlined. It is hoped that architects and builders generally will proceed much further with this study and that the face brick industry will have their full cooperation in keeping dry the face brick walls of buildings yet to be constructed.

EFFLORESCENCE ON FACE BRICK WALLS

(Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce)

THE accumulation of salts, usually sulfates, upon the outer surface of the wall of a building, is commonly referred to as "white wash" or "efflorescence." These salts may exist in the mortar used with the face brick, in the face brick themselves, and usually to a greater extent in the softer burned brick and hollow tile backing. They may be present in any concrete mortar materials, cement block, etc., used in the backing.

Causes of efflorescence

During a cool and humid season of the year when the wall is repeatedly exposed to rain, moisture penetrates far back of the facing and takes into solution some of these soluble salts from both the back-up and the facing materials. As soon as the weather becomes favorable for evaporation of this accumulated moisture, as in the spring of the year, these salts are carried outward and are deposited on the face brick. A wall under process of construction is particularly apt to absorb a considerable amount of moisture. Every precaution should be taken to keep an unfinished wall covered and protected from rain or snow during the process of construction. Moisture so accumulated in the wall brings the salts to the outer wall surface to such an extent that the efflorescence becomes very noticeable before the building is even completed. The layman who sees only the visible salts on the outer wall, may not consider any of the materials in the wall, beyond what he actually sees, as contributing factors.

Purpose of investigation

In order to get the essential facts concerning the mechanism of the development of efflorescence, the American Face Brick Association conducted an investigation at the Bureau of Standards in accordance with that institution's Research Associate plan.

Method of procedure

To obtain information concerning the development of efflorescence, it was thought to be expedient to study primarily the materials, brick and mortar. Whatever

facts were found with respect to intervening cement or lime mortar joints in the outer wall of face brick as concerns efflorescence would apply to such lime or cement mortar if used with back-up materials, provided of course that water could penetrate into the backing. Whatever factors there are in plant procedures that would tend to introduce soluble salts in face brick would also obtain in the process of manufacture of any heavy clay product manufactured under similar conditions.

In order to study the parts that mortar materials as well as face brick play in the development of efflorescence on a wall, there were selected for the purpose four types each of well known and extensively used limes, portland cements and bricklayers' cements. There were also selected from various parts of the United States fifty-five different types of face brick.

The brick and mortar materials were used in test panels made as follows: three brick of the same type were laid up, one above another, with intervening joints of a mortar prepared from one volume of lime or cement mixed with three volumes of Standard Ottawa Sand. The mortar joints were approximately $\frac{1}{2}$ inch in thickness.

Two such panels were constructed with each type of brick laid up with a given lime, portland cement or bricklayers' cement mortar. Each pair of panels constituted a single test. Twelve tests of twenty-four panels were made with each of the four limes and cements, thus bringing the total number of panels tested to 288.

After the panels were constructed they were allowed to set and dry on the floor of the laboratory before being subjected to the test for efflorescence. At the end of three weeks, each pair of panels was set in a separate pan containing about one inch of distilled water, one panel of each pair being set vertically and the other horizontally. Water was added to the pans from time to time as required to replenish loss by evaporation. The tests were continued for a period of six months.

Simultaneously with these panel tests individual tests for efflorescence were made with the brick of the same types as those used in the panels. Each lot of six brick representing one manufacturer's product was tested in a pan separate from the others. The brick were set vertically in the pan and in about an inch of distilled water and the tests in all cases were continued for a period of six months.

Results of tests for efflorescence

It must be realized that the tests above described were such as to provide conditions most favorable for the development of efflorescence. If the same brick and intervening mortar joints had been placed in the outer wall of a building, rainfall from time to time would have tended to wash off the deposits of salts on the surface. However, in this case there was in each individual test a steady accumulation of such salts on the dry portions of the panels and no removal of accumulated salts during the six months' period of the tests.

The total number of different types of face brick used in the panels was thirty-two. Of this number fifteen did and seventeen did not develop any noticeable efflorescence during the six months' tests made on the individual brick themselves and not in contact with any mortar. The seventeen types which did not develop any efflorescence when so tested individually did develop noticeable efflorescence with at least one of the various types of mortars. Both the face brick and the cements and limes used in these tests were so chosen as to be as nearly representative as possible of such building materials as used in the United States. The results should therefore be very indicative of the contribution that each material would make toward the development of efflorescence on a wall.

The tests were rigorous and extended over a comparatively long period of time. The gradually accumulating salts on the dry surfaces of the panels or of the individual brick were not removed by rain, a condition which obtains when such materials are used in the wall of a building. In view of the fact that $\frac{17}{32}$ or fifty-three per cent of the types of face brick developed no efflorescence during the six months when tested individually (even though the tests were much more severe than any actual conditions existing in the wall), but did develop noticeable efflorescence when laid up with at least one type of mortar, it must be concluded that the face brick manufacturers have to a considerable extent reduced any tendency on the part of their product to develop efflorescence.

Methods of reducing the extent to which lime and cement materials may contribute to efflorescence

Theoretically, any possible contribution to wall efflorescence on the part of mortar materials may be prevented or decreased if the mortar could be rendered more impermeable to water. It is not possible to fill all of the voids, but it is possible that the presence of a certain substance or substances introduced into such voids could lessen the passage of water due to capillarity. It is reasonable to assume that if little or no water can enter mortar materials, there can be no leaching out to any appreciable extent of any salts which they contain.

Experimental

A relatively soft and porous type of brick was used throughout in all of the tests of mortars containing the water repellent substances. Excepting those tests wherein a cement was used which already contained the water repellent substance, the mortars were made either with portland cement or lime, or mixtures of lime and cement, together with sand. The relative proportions of the mortar materials were such that the volume ratio of cement or of lime, or of the lime plus cement (if mixtures were used), to sand was one to three. Excepting those trials made wherein a cement was used to which the water

repellent material had already been added at the factory and excepting also those trials in which diatomaceous earth was substituted in part for sand, the amount of the water repellent substance used was either that as specified by the manufacturer, if it had been purchased on the market, or else (if it were not a material made solely for this purpose) an amount of it equal to two per cent by weight of the cement or of the lime or of the lime plus the cement was used.

The water repellent materials were added directly to the mortar materials at the time of mixing. Distilled water was used in such quantities that upon thorough mixing, the mortar had the desired consistency and was thoroughly workable.

Six brick laid up with the mortar, giving five mortar joints, constituted a panel. After being constructed, the panel was allowed to set and dry on the laboratory floor for a period of three weeks prior to beginning the test. After this length of time, the panel was set (brick flatwise) in a shallow pan, the joints being parallel to the base of the pan. The lower brick was about half submerged in a saturated solution of sodium sulfate which was poured into the pan upon beginning the test. For a period of six months the level of the solution of sodium sulfate was kept fairly constant and observations were taken from time to time, noting any upward progress of the salt solution through the mortar joints. When penetration did occur, the crystals of sodium sulfate appeared upon the second, third, etc., brick from the bottom according as the rate of penetration was slow or rapid. The test was continued over a period of six months.

Results of tests on water repellent materials

For the most part, all of the compounds used tended to decrease the rate of penetration of the salt solution through the mortar joints. The inert materials, clay and diatomaceous earth did not entirely prevent penetration in all cases, but were, however, more or less effective. Ammonium, aluminum, and calcium stearate were equally effective and no salts penetrated beyond the first mortar joints in any panel in which any one of these substances was used.

A wall in which these water repellent substances have been used must not be considered as being thoroughly waterproof. Rain may penetrate through face brick to the back-up materials, take salts in these materials into solution and then carry them back to the outer wall during the subsequent process of the drying of the wall. The purpose of the stearates is only to render less likely the contributing of the various mortar materials used in the entire wall to the development of efflorescence on the outer wall. Furthermore it is evident that in order for this condition to be realized, the water repellent substances must be used in all of the mortar in the wall, in the backing as well as in the mortar used with the face brick.

Other means of reducing efflorescence

Since two conditions must exist for efflorescence to appear on the outer wall, it is obvious that there are two means of reducing efflorescence. One of these conditions is the presence of salts in the materials in the wall, from front to back. The other condition is the penetration of moisture into the wall, taking these salts into solution. The manufacturer should concern himself with the first condition mentioned. The architect and builder can relieve the second, penetration of water into the wall, to some extent at least.

The use of the stearates as water-repellent substances in the mortar is suggested. In addition to this, careful and prompt pointing and waterproofing of parapet walls, copings, etc., and flashing to prevent the penetration of water into the walls will also help. In the case of parapet walls, it is well to carry the flashing completely through the wall at one or two courses above the roof level. The parapet wall is then completely separated by an impervious membrane from the other portion of the wall and consequently water can not penetrate down into the wall and later be drawn up to the top of the parapet by capillarity. Architects should seek still further to avoid trouble by waterproofing the entire inner side of the wall and should use impervious coping with carefully pointed joints.

The manufacturers of face brick are able to reduce to a negligible quantity soluble salts in their product, chiefly by means of special burning procedures. Often, also, they have made use of barium compounds, adding them to the clay to render the sulfates insoluble. To a lesser degree, perhaps, such measures can be used in the manufacture of the clay products used as back-up materials, although the selling price of such products does not warrant the application of the comparatively expensive measures as used in the manufacture of face brick to eliminate any soluble salts.

The builder who would guard especially against the occurrence of efflorescence on the outer wall should take into consideration each and every material that is to compose the entire wall. If any tests are to be made to determine the presence of soluble salts, every material in the wall should be so tested and it is equally important that every necessary precaution be taken to reduce penetration of water into the wall to a minimum.

A more detailed report covering the work done has been published by the Bureau of Standards as Technologic Paper No. 370, under the title "Cause and Prevention of Kiln and Dry-House Scum and of Efflorescence on Face Brick Walls."

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